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KATAWARE : FROM PROTOTYPE TO VERSION 1

DEVELOPMENT OF THE MODEL FOLLOWING THE ITERATIVE PROCESS OF COMPANION-MODELLING

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A STAKEHOLDER DRIVEN PROCESS TO DEVELOP A CATCHMENT MANAGEMENT PLAN FOR THE KAT RIVER VALLEY

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Preface

This report illustrates version 1 (V1) of the multi-agent system (MAS) KatAWARE, which is being developed within the Water Research Commission (WRC) project "A Stakeholder driven process to develop a Catchment Management Plan for the Kat River Valley". KatAWARE is being developed through a participatory action research approach called Companion Modelling (ComMod) (Farolfi-Rowntree, 2005). According to this approach an iterative process of modeling and discussion take place between the research team and the local stakeholders. This process results in several versions of the model that should converge into a common and validated representation of the reality for local stakeholders participating in the co-construction of the model.

A previous report (Farolfi-Bonté, 2005) provided a thorough description of the KatAWARE Prototype (from now on: KatAWARE P).

Most of the changes introduced in KatAWARE V1 are the result of the discussions that took place during a workshop held with the Kat Water Users Association (WUA) in Fort Beaufort in June 2005 and dedicated to the presentation of KatAWARE P (Burt et al. 2005).

The main changes with respect to KatAWARE P refer to the hydrologic component of the system, the new production functions that consider water shortage effects, the hierarchy in water provision for agents within a subcatchment, the introduction of regulatory framework (water licencing system), and minor adjustments in the financial, agronomic and socio-economic components of the model.

New scenarios were also tested and some improvements in the interfaces were introduced.

This report is organized in six chapters, all of them illustrating changes from KatAWARE P to KatAWARE V1 in a specific component of the model: the first chapter describes the changes in the model structure; chapter 2 depicts changes in the calibration of water supply, whilst chapter 3 refers to calibration of water demand. Chapter 4 is dedicated to the new framework of water licensing; Chapter 5 describes the new scenarios and finally chapter 6 illustrates the changes in output representations and model's interfaces.

1. MODEL STRUCTURE

1.1 Framework of KatAWARE (V1)

Version 1 of KatAWARE is referred here as KatAWARE V1. Unified Modelling Language (UML) diagrams present the concepts described in the next paragraphs. A **class diagram** refers to the model's concepts and two **sequence diagrams** refer to the scheduling of the model.

The main model's entities are the same as in the KatAWARE prototype (P); they are described in Farolfi & Bonté, 2005. This paragraph describes only the newly introduced entities and the changes to old entities. V1 class diagram is presented in figure 1.

1.1.1 Spatial Entities

Wards, *Voting-Areas* and *Sub-Catchments* have the same functions in KatAWARE V1 as in KatAWARE P. However, they are calibrated differently and the *Sub-Catchments'* size and shape were modified accordingly to new information and data available.

Sub-Catchments used to represent water supply in KatAWARE V1 are not anymore the "quaternaries" defined by DWAF; the new *Sub-Catchments* are sub-divisions of these quaternaries.

Consequently, a new spatial entity was added, namely the *Quaternary*.

- ***Quaternary***

The Quaternary has two main characteristics:

- *code*, corresponding to the name of the quaternary (Q94A to Q94F)
- *sub-catchments*, corresponding to the set of Sub-Catchments the Quaternary is composed of.

The fact that the new *Sub-Catchments* are sub-divisions of the *Quaternaries* makes it possible to calculate, for each Quaternary, water supply, demand and consumption. Hence, these values are made available by the model for each Quaternary at every time steps of the simulations.

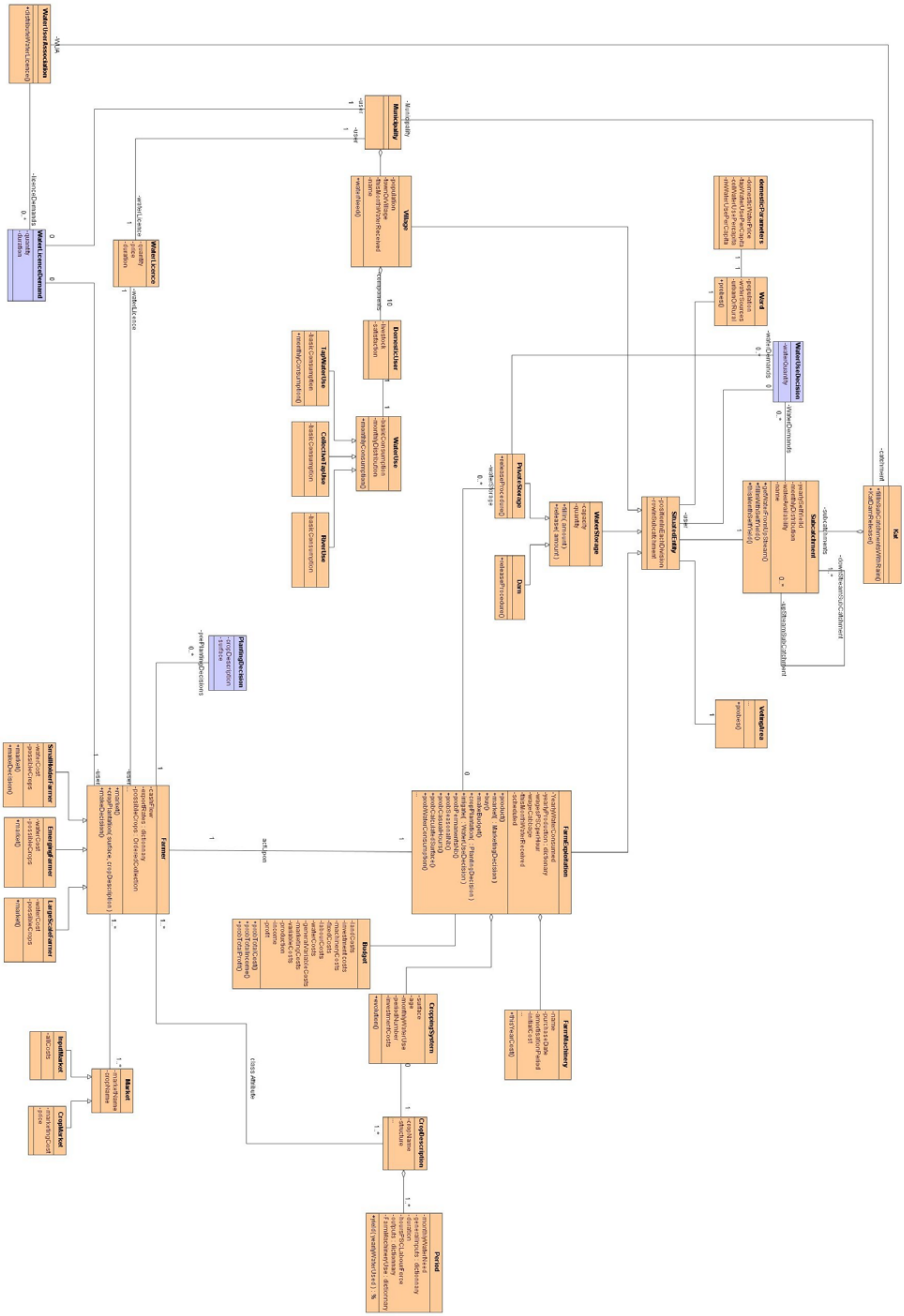


Figure 1: KatAWARE V1 UML class diagram

1.1.2 Situated entities and entities used for water supply modelling

Spatial entities are the same as in KatAWARE P. Water is introduced each month in the system by the *Sub-Catchments* entities. However, in P water storage facilities were incorporated in the "yield" calculation and water storage capacities were not represented as independent entities. In V1, these water storages and their functionning are explicitly represented and calibrated.

- ***Water Storage***

Two types of *Water Storages* can be distinguished in KatAWARE V1: *Dams* and *Private Water Storages*. Both of them have the two following characteristics:

- *capacity*, corresponding to the maximum amount of water that can be contained in the storage;
- *quantity*, corresponding the amount of water contained in the storage at a given moment. (obviously *quantity* ≤ *capacity*)

It is worthwhile noticing that *Water Storage* is a new *Situated Entity* that is able to withdraw water from the environment. In V1, three types of Situated Entities co-exist: The *Farms*, the *Villages* and the *Water Storages*.

One *Dam Water Storage* entity is present in KatAWARE V1 and represents the Seymour Dam placed in the Upper catchment. Two Private Water Storages are included in the Middle and in the Lower catchment respectively.

- ***Changes in Situated Entities* (*Farms*, *Villages* and *Water Storages*)**

All situated entities (*Farms*, *Villages* and *Water Storages*) have a new important characteristic in V1: this is the *row in sub-catchment*, reflecting the position they have on the river path in their respective *Sub-Catchment*.

1.1.3 Entities related to water management institutions and policies

- ***Municipality***

Municipality entity is composed of a set of *Villages* entities. It doesn't have any other characteristic and its role is very limited in the model.

- ***Water User Association***

The *WUA* entity has the two following characteristics:

- *licence demands*, allowing the entity to receive *Water Licence Demands*. It is a set of *Water Licence Demands* from which the *WUA* Entity establishes the *Water Licences* attributed to each user. These *Water Licence Demands* are described further.
- *catchment*, linking the *WUA* entity to the *Catchment* entity. Meaning that it is possible to define the *WUA* entity decision making as a function of the *Catchment* situation.

- ***Water Licence Demands***

The Water Licence Demands have the three following characteristics:

- *quantity*, corresponding to the amount of water asked in cubic meters per year;
- *duration*, corresponding to the number of years the user asks the licence for;
- *user*, corresponding to the water user that submitted the *Water Licence Demand*.

The water users represented in the model and potentially allowed to get water licences from the WUA are the *Farmers* and the *Municipality*. Both ask licences to the *WUA* entity via *Water*

Licence Demands. On the basis of these *Water Licence Demands*, the *WUA* entity distributes the *Licences* to these users according to the policy/strategy defined by the modeller.

It is worthwhile noticing that, due to still insufficient information on the functionning of the emerging WUA, in V1 water users always receive the *Licence* they asked.

- ***Water Licence***

A Water Licence entity has the two following characteristics:

- *quantity*, corresponding to the annual amount of water the user is allowed to use (in cubic meters);
- *duration*, corresponding to the number of years the Licence is valid.

- **Changes in *Farm* and *Village***

A new characteristic was added to *Village* and *Farm* definition to regulate the use of the *Dam*.

- *scheduled or unscheduled* statement, telling if the user (*Farm* or *Village*) can ask or not for Dam water releases.

1.1.4 Entities representing decisions

In V1 it was chosen to formalise the decisions taken by the actors in order to study more precisely the gap between what agents want to do and what they actually do facing a certain number of constraints.

- ***Water Use Decision***

The *Water Use Decision* has the two following characteristics:

- *water quantity* measured in cubic meters per month,
- *user*, corresponding to the entity "asking for water" (*Village*, *Water Storage* or *Farm*).

Every entity "using" water in the model can receive water from the system only by creating a *Water Use Decision* and sending it to the water source (*Sub-Catchment* or *Water Storage*). These entities, able to withdraw water and create *Water Use Decisions*, are the *Situated Entities* in the class diagram, namely the *Water Storages,* the *Farms* and the *Villages*. Hence, *Villages* and *Water Storages* withdraw water from *Sub-Catchments*, whilst *Farmers* either from *Sub-Catchments* or from *Private Storages*. Then, they will be able to withdraw the total amount of water demanded (*water quantity*) or less (if not available).

- ***Planting Decision***

The *Planting Decision* has the two following characteristics:

- *crop description*, being the name of a *Crop Description* defined in KatAWARE V1;
- *surface,* corresponding to a surface measured in hectares.

The *Planting Decisions* represent entirely all the socio-economic choices the *Farmer* agents make each year according to their personal strategies. They have been introduced in this new version of the model in order to allow the *Farmer* agent to modify its personal decisions according to the water licences it receives from the *Water User Association* entity.

It is worthwhile noticing that, due to still insufficient information on the functionning of the emerging WUA, the *Farmers* agents always implement the choices of their *Planting Decisions*.

1.1.5 Other changes in entities

- ***Catchment***

The entity Catchment has been created to regroup all *Sub-Catchments*.

- ***Farm organisation***

In *Farms* entity, some concepts' names have been changed in order to separate clearly economic values from the real objects leading to costs or incomes. Hence, "*Fixed Capitals*" term has been replaced by "*Farm Machineries*".

1.2 KatAWARE V1 initializing

In V1, all data are imported from initialising files to create and calibrate the above-mentioned entities during the initialisation phase. Then, SIG maps were used to draw the spatial entities (*Sub-Catchments*, *Wards* and *Voting Areas*) and to place situated entities (*Farms*, *Villages* and *Water Storages*) on the topologic support.

1.3 KatAWARE V1 scheduling

As in KatAWARE P, also in V1 there are two time-steps: monthly and yearly. For each time step, an UML sequence diagram is presented figures 2 and 3.

1.3.1 Monthly step, when the hydrological situation evolves

Monthly step is divided in four stages.

- **Stage 1:**

Natural run-off (from rain) flows in the catchment via the river (*Sub-Catchments water availability*). It flows from upstream *Sub-Catchments* to downstream ones and, inside a given *Sub-Catchment*, from the upstream *Situated Entity* (*Farm, Village* or *Sub-Catchment*) to the downstream *Situated Entity*. *Situated Entities* withdraw the amount of water they need.

- **Stage 2:**

If a certain number of conditions are gathered, the *Dam* releases water in the river. This water flows in the *Sub-Catchments* placed downstream the *Dam*.

- **Stage 3:**

Agents owning *Private Storages* can withdraw water from them.

- **Stage 4:**

At this stage, it is not possible anymore to withdraw water from any source. Entities carry out their monthly socio-economic activities according to the water they received (or not) during the above-mentioned stages.

1.3.2 Yearly step, when socio-economic decisions are taken

In the yearly time step, one can find the same activities as in KatAWARE P. It is worthwhile noticing that some of these activies are not defined the same way, e.g. the calculation of the annual production.

Furthermore, activities linked to the framework of water management policies modelling have been added, like the *Water Licences* attributions by the *Water User Association* entity.

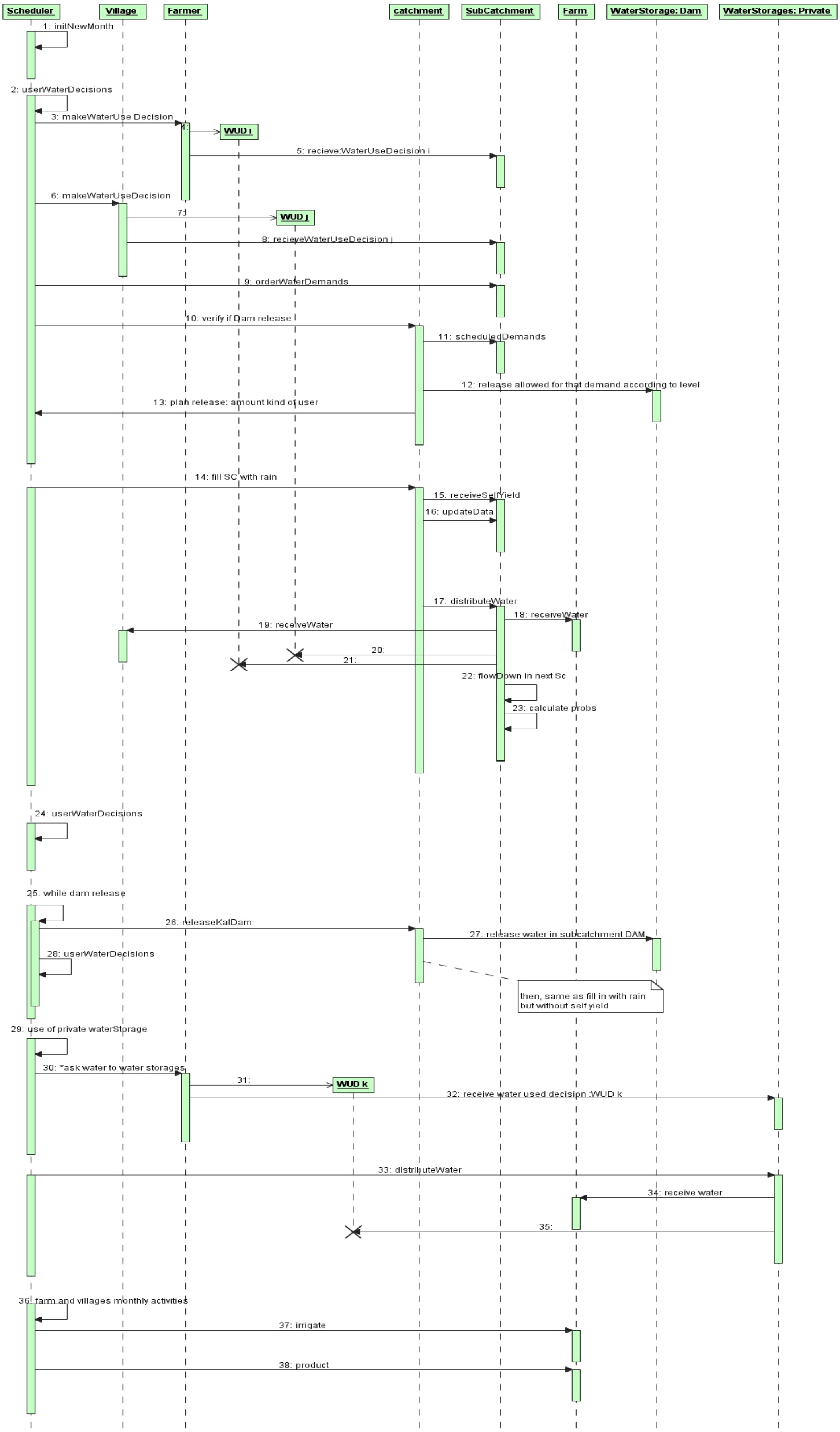


Figure 2: KatAWARE V1 monthly step UML sequence diagram

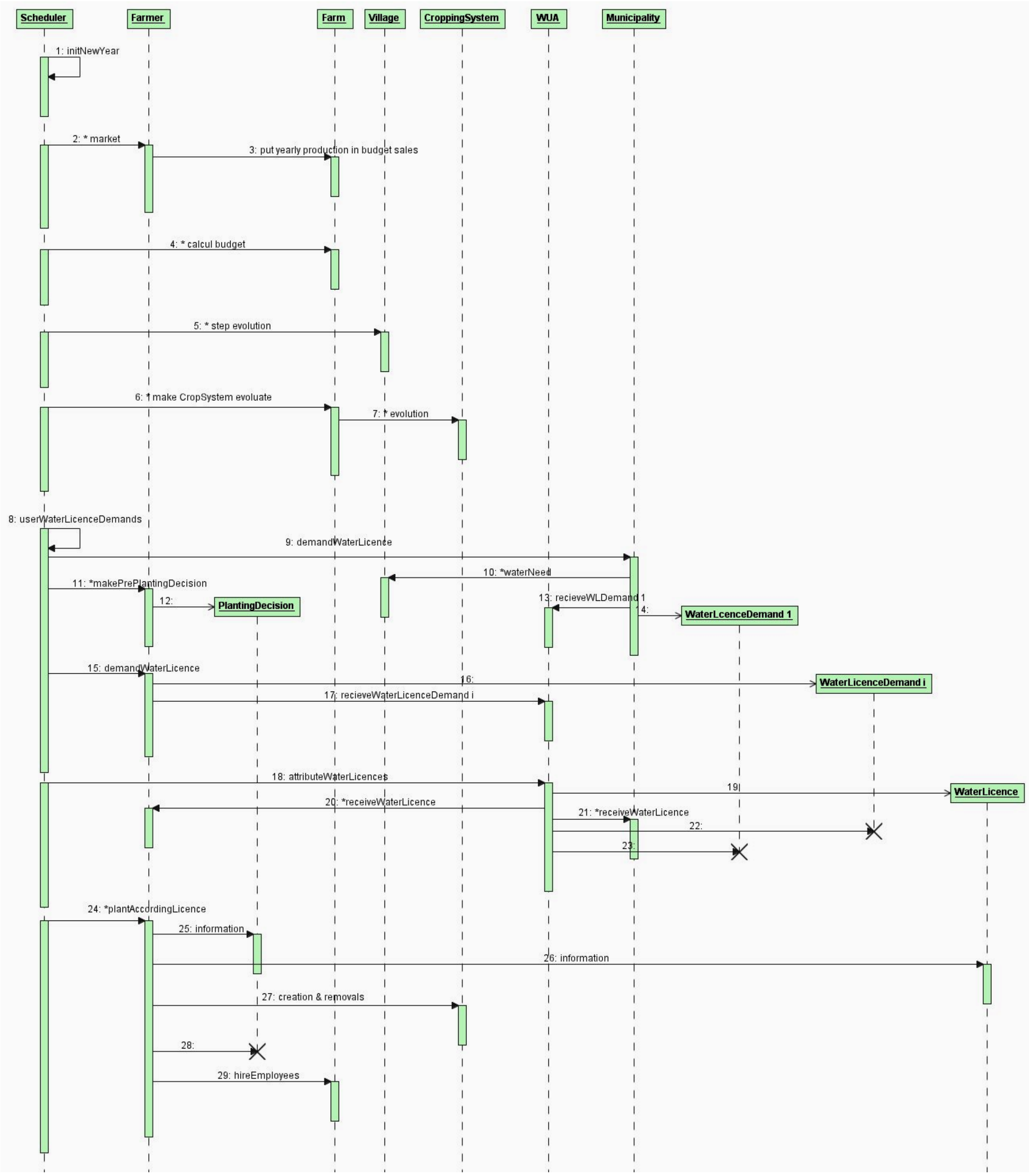


Figure 3: KatAWARE yearly step UML sequence diagram

1.4 Representation of water supply and water demand in KatAWARE V1

1.4.1 Water demand representation

As in KatAWARE P, *Villages* and *Farms* entities are entirely responsible of water demand. Hence, water demand can be calculated at all spatial scales (*Sub-Catchments*, *Wards*, *Voting-Areas* or *Catchment*) aggregating all the demands of the *occupants* of a given spatial entity.

1.4.2 Water supply representation

Water supply of the system was radically modified. Water is still supplied to the system via the *Sub-Catchments* entities, as a yearly amount of water attributed to each *Sub*-C*atchment* and distributed over the year according to a *monthly distribution*.

However, the introduction of *Water Storages* obliges to separate natural run-off from total run-off, and the relative position of the users (upstream or downstream) is now taken into account within the *Sub-Catchments*. All the occupants of a *Sub-Catchment* are not anymore at the same level of priority for their water availability. These two important issues were explicitly raised by several stakeholders when the prototype model was presented to the Kat River Water User Association (Burt et al., June 2005).

1.4.2.1 Role of the Water Storages in the model's water supply

Two types of *Water Storages* have been defined, namely *Dams* and *Private Storages*. They have the same main characteristics as told in the entities description but don't have the same relations with the environment. They have the same filling-in process: they withdraw water from the river (*Sub-Catchment* entities) until they are full (*quantity = capacity*). But they don't have the same process to release water. First of all, the releasing procedures are different and, more importantly, the released water does not have the same destination.

Water released from the *Private Storages* can only be used by the owners of the *Water Storage* to satisfy their own demands. Conversely, water released from the *Dam* can either be used by the population of the *Dam's Sub-Catchment* or flow through the river (*Sub-Catchments*) and then be available for every downstream users.

Water Storages' operating rules (how releases and filling are controlled) are described in the water supply calibration section.

1.4.2.2 The Catchment scale

Due to the presence of the *Water Storages*, two sources of water are now available for the users (*Villages* and *Farms*): 1°) water stored in the *Water Storages* and 2°) rainfall water represented by the *natural run-off* of the *Sub-Catchments* (calculated differently in P).

Furthermore, whereas in every scenario of KatAWARE P yearly water supply provided to the whole system was constant year after year during the whole simulation, in KatAWARE V1 this amount of water (set of Yss_s in equation [1]) can be changed to build scenarios.

After these changes, the expression of the water available in the catchment at any moment is now the following:

$$Cs_{i,j} = \sum_{s \in (Sc)} Yss_{s,i} \times Ms_{s,j} + \sum_{ws \in (WS)} Q_{ws,i,j} \qquad [1]$$

Where:

$Csi_{,j}$ = Whole catchment's water supply for month "j" of year "i"

(Sc) = System's *Sub-Catchments* index's set

$Yss_{s,i}$ = Water brought to the system by *sub-Catchment* "s", year "i" (*yearly self yield* of this *Sub-catchment*)

$Ms_{s,j}$ = “s” *Sub-catchment’s* monthly distribution of annual yield at month “j”

(WS) = Set of the *Water Storages* present in the system

$Q_{ws,i,j}$ = Amount of water stored in the “sw” *Water Storage* at month “j” of year “i”

It is worthwhile noticing that in KatAWARE P water supply at the catchment scale was totally independent of what happened the previous years, while now the catchment water supply depends on its “history” via the *Water Storages’* levels.

Access to water stored in *Water Storage* is regulated by specific rules, in the reality as well as in the model. Regulation rules defined in the model are described in the section of this report describing the water supply calibration. The reader will also note in that section how the *yield* calculation has been changed.

1.4.2.3 The Sub-Catchment scale

Each month, water available in a *Sub-Catchment* can be calculated by summing this *Sub-Catchment water-availability* (self yield + water flowing from upstream) and the water stored in this *Sub-Catchment’s Water Storages*.

Hence, each month, water supplied to a *Sub-Catchment* can be given by the following equation:

$$Ss_{s,i,j} = Yss_{s,i} \times Ms_{s,j} + \sum_{u \in (Su)_s} O_{u,i,j} + \sum_{ws \in (WS)_s} Q_{ws,i,j} \qquad [2]$$

Where:

$Ss_{s,i,j}$ = *Sub-Catchment* “s” total supply for year “i”, month “j”

$Yss_{s,i}$ = *Sub-Catchment* “s” *yearly self yield* at year “i”

Ms_{sj} = *Sub-Catchment* “s” *monthly distribution* at month “j”

$(Su)_s$ = *Sub-Catchment* “s” *upstream Sub-catchments’* index set

$O_{u,i,j}$ = *Sub-Catchment* “u” outflow for year “i” month “j”

$(WS)_s$ = Set of the *Water Storages* present in the *Sub-Catchment* “s”

$Q_{ws,i,j}$ = Amount of water stored in the “sw” *Water Storage* at beginning of month “j” of year “i”

It is important noticing that the presence of the *Water Storages* has a huge impact on the quantities of water arriving from the upstream *Sub-Catchments* (O terms in equation [2]). In the previous version of the model (KatAWARE P), it was possible to define each of these terms as the difference between the supply and the demand of the upstream *Sub-Catchments*. In other terms, the amount of water flowing out of a *Sub-Catchment* was the water that arrived in the *Sub-Catchment* (supply) minus the water consumed in this *Sub-Catchment* (demand). It is not anymore the case. Now, these quantities (outflows) depend also on the quantity of water used to fill in the upstream *Sub-Catchments’ Water Storages* (the *Dam* and the *Private Storages*), and obviously the quantity released in the river in the most upstream *Sub-Catchment* by the *Dam*.

In addition, as it is explained later, water is now supplied to each water user (*Farm* or *Village*) according to its position in the *Sub-Catchment* and also according to the possible access it has to a *Private Storage*. Because some users have acces to *Private Storages* and others don't, it may happen that even if the water supply of a *Sub-Catchment* is higher than its total demand for a given month, some users of this *Sub-Catchment* might not have their demands satisfied during a specific month. For this reason, water demand and water consumption was distinguished for each agent.

Water consumed, and not anymore water demanded, is important in the calculation of Sub-Catchments'outflows. The outflow of *Sub-Catchment* "u" at month "j" of year "i" is the following:

$$O_{u,i,j} = Ss_{u,i,j} - Sc_{u,i,j} - \sum_{ws \in (WS)_u} Q_{ws,i,j} - \sum_{ws \in (WS)_u} \Delta Q_{ws,i,j} \qquad [3]$$

Where:

$Ss_{u,i,j}$ = *Sub-Catchment* "u" total supply for year "i" month "j" as defined previously

$Sc_{u,i,j}$ = *Sub-Catchment* "u" water **consumption**, year "i", month "j"

$(WS)_u$ = Set of the *Water Storages* present in the *Sub-Catchment* "u"

$Q_{ws,i,j}$ = Amount of water stored in the "sw" *Water Storage* at beginning of month "j" of year "i"

$\Delta Q_{ws,i,j}$ = Algebraic variation of the level of the "sw" *Water Storage* at month "j" of year "i" (*quantity* at the end of the month – *quantity* at the beginning)

1.4.2.4 The agent scale

In V1 of the model, a new level of precision is considered for water supply. Depending on its characteristics, each water user (*Farm* or *Village*) can withdraw water from one of the two sources of the model: the river (*Sub-Catchments' water availability*) and the *Water Storages*.

As indicated above, an order was defined for the access to river water (*Sub-Catchments' water availability*), according to the relative position (upstream, downstream) of the water users (Farms and Villages) and the *Water Storages*. Entities sitatuted downstream have to wait that entities situated upstream have satisfied their water needs and have only access to the remaining water.

Regarding access to water stored in the *Water Storages*, two different cases exist: water stored in the *Dam*, and water stored in *Private Storages*.

Water stored in the *Dam* has to be released in the river and users can have access to it only by withdrawing it from the river from their positions. This water is seen as river water (*Sub-Catchments' water availabilities*) by the situated entities (*Villages*, *Farms* and *Water Storages*). These releases from the *Dam* are directed according a specific process described in the water supply calibration chapter.

Water stored in the *Private Storages* is directly withdrawn by the *Water Storages* owners only. The way how several owners of a same *Private Storage* share the water is also described in the water supply calibration chapter.

Hence, each month, water supplied to a given Situated Entity is the following:

$$As_{a,i,j} = Rs_{a,i,j} + WSs_{a,i,j} \qquad [4]$$

where:

$As_{a,i,j}$ = total amount of water supplied to agent “a”, month “j” of year “i”

$Rs_{a,i,j}$ = amount of water withdrawn in the river by agent “a”, month “j”, year “i”

$WSs_{a,i,j}$ = amount of water withdrawn in *Water Storages* by “a”, month “j”, year “i”

with:

$$Rs_{a,i,j} = Yss_{s,i} \times Ms_{s,j} + \sum_{u \in (Su)_s} O_{u,i,j} + \sum_{ws \in (WSU)_a} \Delta Q_{ws,i,j} - \sum_{au \in (AU)_a} Ac_{au,i,j} \qquad [5]$$

where:

« s »= *Sub-Catchment* in which the entity « a » is situated

$Yss_{s,i}$ x $Ms_{s,j}$ = self yield of the *Sub-Catchment* “s” for month “j” of year “i”

$(Su)_s$ = Set of the “s” Sub-Catchment’s upstream *Sub-Catchments*

$O_{u,i,j}$ = Outflow of Sub-Catchment “u”, month “j”, year “i”

$(WSU)_a$ = Set of the *Water Storages* situated upstream agent “a” in its *Sub-Catchment*

$\Delta Q_{ws,i,j}$ = “ws” *Water Storage*’s quantity variation (initial_quantity – final_quantity) for month “j” , year “i”

$(AU)_a$ = Set of agents (*Farms* or *Villages*) situated upstream agent “a” in its *Sub-Catchment*

$Ac_{au,i,j}$ = “au” agent’s consumption for month « j », year “i”

and:

$$WSs_{a,i,j} = \sum_{ws \in (WS)_a} Q_{ws,a,i,j} \qquad [6]$$

where:

(WS)a = set of « a » agent’s *Private Storage*;

$Q_{ws,a,i,j}$ = Quantity available in *Private Storage* “ws” for agent[1] “a” at month “j” of year “i”.

Let’s note that the $As_{a,i,j}$ quantity represents the water quantity arriving to the agent at month i of year j, and, as said previously, some users can control *Dam* releases (namely *scheduled* agents). This has two important consequences:

Firstly, such users have a more important water supply because they can have access to thewater stored in the *Dam* according to the *Dam* operating rules.

Secondly, water available in the river for users situated upstream scheduled users depends on *scheduled* users water uses.

[1] Depends on the demands of other owners of the *Private Storage*. How water is distributed among the users of a *Private Storage* is explain in the chapter about water supply calibration.

2 CALIBRATION OF WATER SUPPLY IN KatAWARE VERSION 1

2.1 New Sub-Catchments' representation

In V1, a new representation of the cathchment is used. It was drawn by the Rhodes University hydrology research team. (Hughes, 2005). The new model distinguishes 14 *Sub-Catchment*s instead of the six identified in P. The new Sub-Catchments are sub-divisions of the Quaternaries used in KatAWARE P.

One can notice that this new drawing increase the accuracy level of the water supply model. It allows in particular representing areas depending on the tributaries and not only on the main river. The V1's Sub-Catchments and watercourse system are represented figure 4.

These Sub-Catchments have been defined according to the ecological needs of the different part of the Kat River Catchment. Meaning that within a given Sub-Catchment, ecological needs will be considered as homogeneous and it will be possible to calculate the ecological reserve.

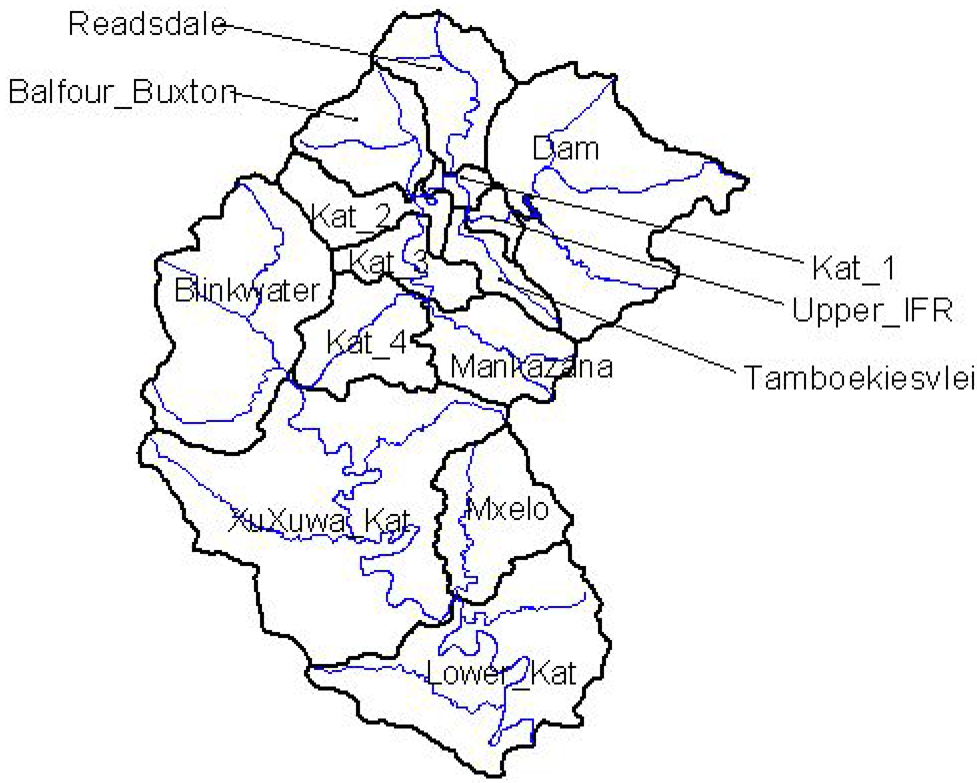


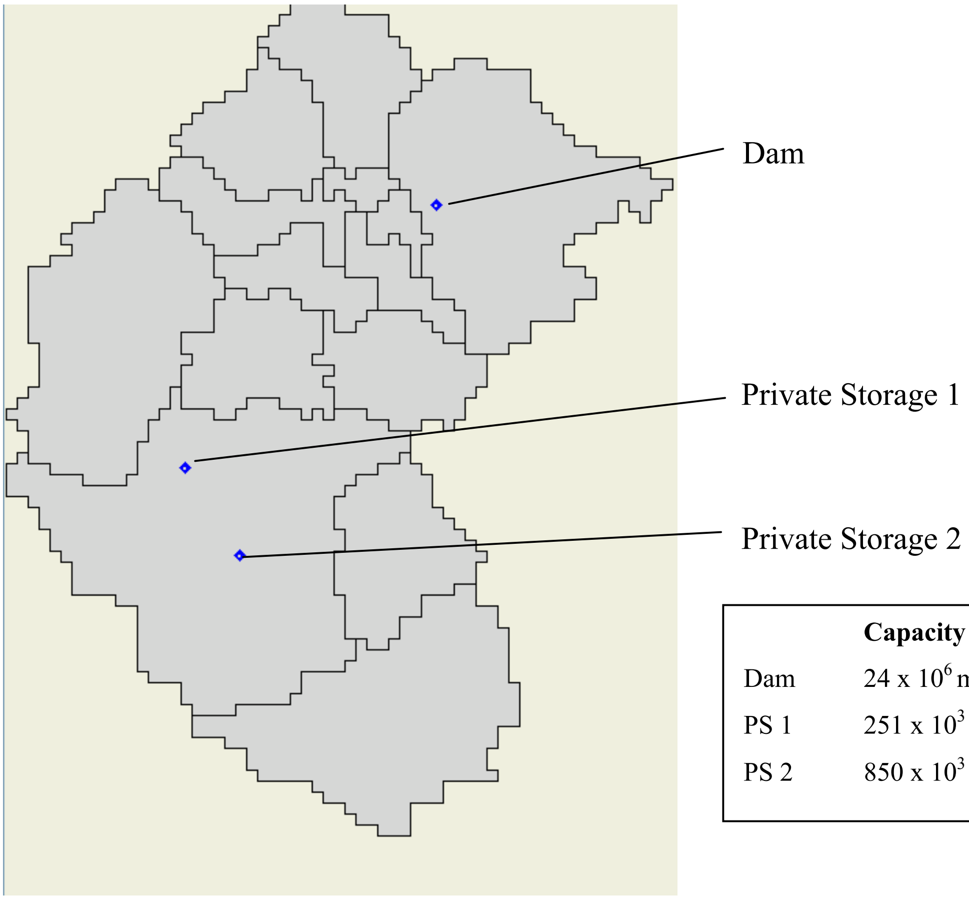
Figure 4: Kat new sub-catchments and watercourse system (WR90)

2.2 Water-Storages

2.2.1 Position and capacity

Three *Water Storage* entities were introduced: The *Dam* in the upper Kat ("Dam" *Sub-Catchment*) and two *Private Storages* in the lower kat ("Xuxuwa kat" *Sub-Catchment*). Their capacities and placement can be observed figure 5.

The Seymour Dam operator (DWAF) confirmed the *Dam*'s capacity (cf. Operation and Maintenance Manual – Kat River Dam) and the *Private Storages*'s capacities were calculated from estimations of large scale farmers, owners of these weirs. (Farolfi & Abrams, 2005)



	Capacity	Owner
Dam	24×10^6 m^3	DWAF
PS 1	251×10^3 m^3	Scheduled farmer
PS 2	850×10^3 m^3	Unscheduled farmers

Figure 5: Water Storages in Kat-AWARE V1

2.2.2 Operating rules

Both types of Water Storages (*Private Storages* and *Dam*) have the same filling process. They withdraw water from the river (*Sub-Catchment's water availability* at their level) until they are full. It means that river water can flow downstream a *Water Storage* only if the *Water Storage* is full (quantity = capacity) or if the *Water Storage* is the *Dam* (*Private Storages* can't release water in the river) and there is a water release.

So, *Water Storages'* filling in process is relatively simple and automatic. On the other hand, water releases are controlled by agents having access to the *Water Storages* and are regulated by rules. The way agents can have access to the *Water Storages* depends on the type of *Water Storage* itself (*Dam* or *Private Storage*) and is described in the next paragraphs for both types.

2.2.2.1 Private Storages releases

- ***Private Storages'* owners**

A *Private Storage* can have one or several owners. In V1, *Private Storages* represent Farms dams or weirs. Figure 5 indicates private storages locations and characteristics.

- ***Private Storages'* operating rules**

As above-mentioned, *Private Storages* are aggregations of the Lower-Kat water storages in two *Water Storages*. It would have been more accurate to attribute to each *Farm*, a *Water Storage* having the capacity needed by the represented farm. It was judged un-necessary to reach such a level of accuracy. Nevertheless, the release procedure implies that the *Farms* requiring a higher amount of water have accordingly access to a more important part of the storage. The release procedure is as follow:

- If enough water is available in the *Private Storage* for all its owners, every one receives the amout of water he needs.
- If there is not enough water, each owner receives a different quantity, calculated as follows (no priority among farmers relying on the same storage facility):

$$water\_received = \frac{total\_demand}{water\_stored} \times water\_needed$$

From field surveys with local large scale farmers owning *Water Storages*, the hypothesis was made that the *Private Storage* owners would withdraw water from their *Water Storages* only if they do not have any other choice. In other terms, unscheduled users withdraw from the storage facility if they do not receive enough water from the river; and scheduled users withdraw from storage facilities if they do not receive enough water from the river and do not have anymore the possibility to ask water releases from the *Dam*.

2.2.2.2 Dam releases

- **Dam's scheduled users**

Water licences, in the way they can be defined from the New Water Act of 1998 (SA, 1998), and corresponding to *Water Licence* in the model, do not exist yet in the Kat. However, another type of licence is still currently used to operate the Seymour dam; it corresponds to the concept of "scheduling". Initially, the process was defined almost exclusively for irrigation purposes. A scheduled area has been identified, inside which each hectare owned allows its owner to ask a certain amount of water from the dam each year (about 6000 m^3/year). This area is presented figure 6 in a map adapted from the SA Explorer Software system (Jhagoroo et al., 2005). Direct surveys allowed establishing which *Farms* represented in the model were scheduled and which were not. A map from KatAWARE V1 presents the *Farms* considered as scheduled and those considered as unscheduled (figure 7).

In the model, the *Villages* representing Fort Beaufort agglomeration are scheduled (*Villages* situated in *Ward* number 21), all other villages are not.

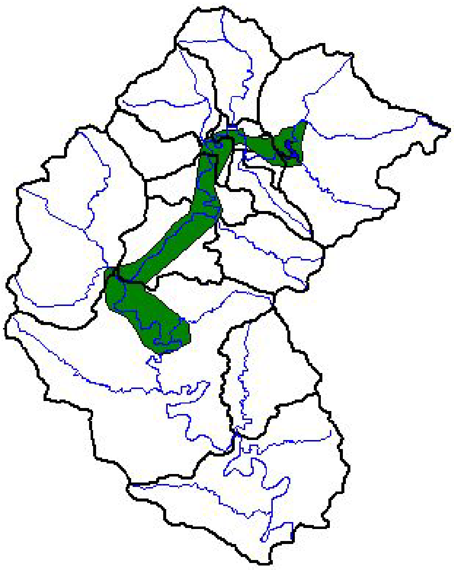


Figure 6: Kat river scheduled area (SA Explorer)

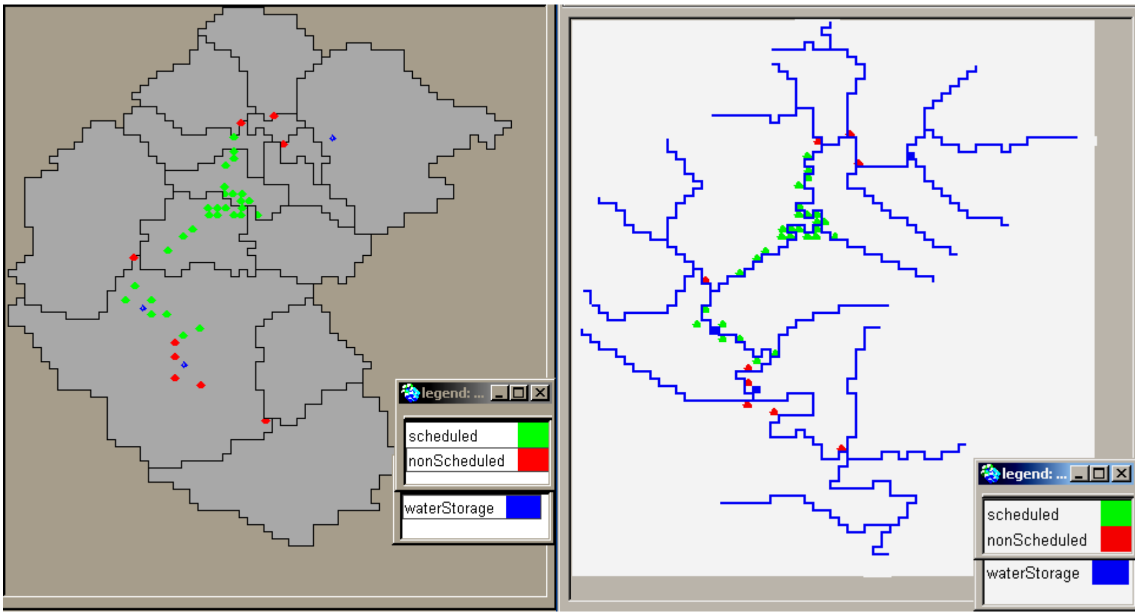


Figure 7: Scheduled and unscheduled Farms in KatAWARE V1

- ***Dam's operating rules***

An accurate documentation of the Seymour dam's operating rules is available at the DWAF office in Seymour (Operation and Maintenance Manual – Kat River Dam). However, after a phone discussion with the Seymour dam operator, it resulted that operating rules are simpler than those described in this procedure. Following this discussion, the operating rules of the modeled *Dam* have been defined as follows:

- If the *Dam* level is higher than 15 % of its capacity, all releases required by scheduled users are accepted.
- If the *Dam* level is lower than 15 % of its capacity, then, only the releases required by scheduled *Village* entities are accepted. In addition, in this scenario only *Villages* (scheduled and unscheduled) entities, and not *Farms* can withdraw from the river the

water released (water flowing in phase 3 of the monthly step); *Farms* and *Water Storage* entities have access only to rain water (water flowing in phase 1 of the monthly step).

A *scheduled* agent (*Farm* or *Village*) asks for a *Dam* release a given month only if the rain water flowing in the river (i.e. flowing in phase 1 of the monthly step) does not satisfy its demand.

Note :

Apart from the case when the Dam level is below 15 % of its capacity, every situated entity in the main river Sub-Catchments can withdraw water from the river in phase 3 of the monthly step. This means that one of these entities (even unscheduled) situated between the Dam release demander and the Dam itself, can withdraw water supposed for the demander. Hence, the demander asks for a new release until upstream users stop withdrawing water because they are satisfied or until the Dam level arrives to its critical level (15%). Only at this stage the monthly activities can proceed further.

In the real world, scheduled farmers can only ask a limited quantity of water from the Dam according to the surface they own in the scheduled area. But because this quantity is almost never consumed, this criterion is not taken into account in the model, where scheduled users can ask as many releases as they need.

2.3 New definition of Sub-Catchments' Run-off

2.3.1 Sub-Catchments' natural run-off (NRO), total run-off (TRO), and water storage capacities

In KatAWARE P, the *Sub-Catchments'* yield represented the total water amount that could reliably (98% insurance of supply) be withdrawn from the Sub-Catchments in a year. This amount of water took into account the eventual presence of water storage facilities in the Sub-Catchments. The larger the water storage capacity, the higher the self yield of the Sub-Catchment. How these values were calculated following DWAF data is explained in the report describing the KatAWARE prototype model (Farolfi & Bonté, 2005).

In KatAWARE V1, the Sub-Catchments' water storage capacities are represented by the *Water Storage* entities; these entities increase the capacity and the stability of water availability in the Sub-Catchments. The possibility to separate the natural run-off (NRO) coming from the rainfall[2] from the storage capacity allows avoiding in this new version the use of the ambiguous term "yield". We can in fact distinguish now NRO and TRO, the latter calculated by adding the storage capacity to NRO.

2.3.2 Insurance of supply

Once again, it is important to keep in mind that annual rainfall is very fluctuating in the Kat. For that reason, it would not seem wise to model average years. In order to allow socio economic activities and insure certain continuity in the provision of water to domestic users, only high levels of insurance of supply were considered in the model.

The three following "representative years" have been defined in the model, from the wetter to the dryer:

- 90 % insurance of supply: corresponding to the worse year that is likely to happen in 10 years;
- 98 % insurance of supply: corresponding to the worse year that is likely to happen in 50 years;

[2] In the Kat almost no groundwater is currently used.

- more than 98 % insurance of supply: corresponding to the worse year that is likely to happen in a 70 years period.

It is worthwhile noticing that because of the presence of *Water Storages,* water supply of a given year depends on the previous years because it depends on the level of the *Water Storages*. In fact, even in the worse scenarios, the *Dam* can supply water during several years before it gets empty. Consequently, the sequence of years in a simulation is very important. For instance, it could be possible to simulate an extreme situation represented by ten consecutive years at a "more than 98 %" level of insurance of supply, even knowing that it is very unlikely that such a situation happens.

For this reason, in KatAWARE V1, it is possible to modify the level of insurance of supply during a simulation (at the beginning of each simulated year), in order to test scenarios where every year or group of years has a level of insurance of supply chosen within the range indicated above.

2.3.3 Data origin

New values used for the new Sub-Catchments' yearly natural run-off were obtained from an hydrologic model constructed by the "Institute of Water Researsh of Rhodes University". This hydrologic model is described in a WRC unpublished paper written within the Kat Project (Hughes, 2005); it simulates the natural run-off of each sub-catchment and is calibrated with data from the local meteorological stations collected between 1920 and 1989.

From the results of this model for these 70 years, three representative years were chosen corresponding to the 3 levels of insurance of supply indicated above (90%; 98%; more than 98%). Figure 8 presents the position of the chosen years compared to the remaining years during the 1920-90 period.

The hydrologic model within KatAWARE V1 calculates for each year and each month the contribution of every sub-catchment to the basin natural run-off. In order to make the model easier, it has been decided to keep the same monthly distribution every year and for all the *Sub-Catchments* (calculated as the mean of the basin natural run-off over the 70 years). Only the yearly natural run-offs vary. Table 1 and figure 9 present the values used.

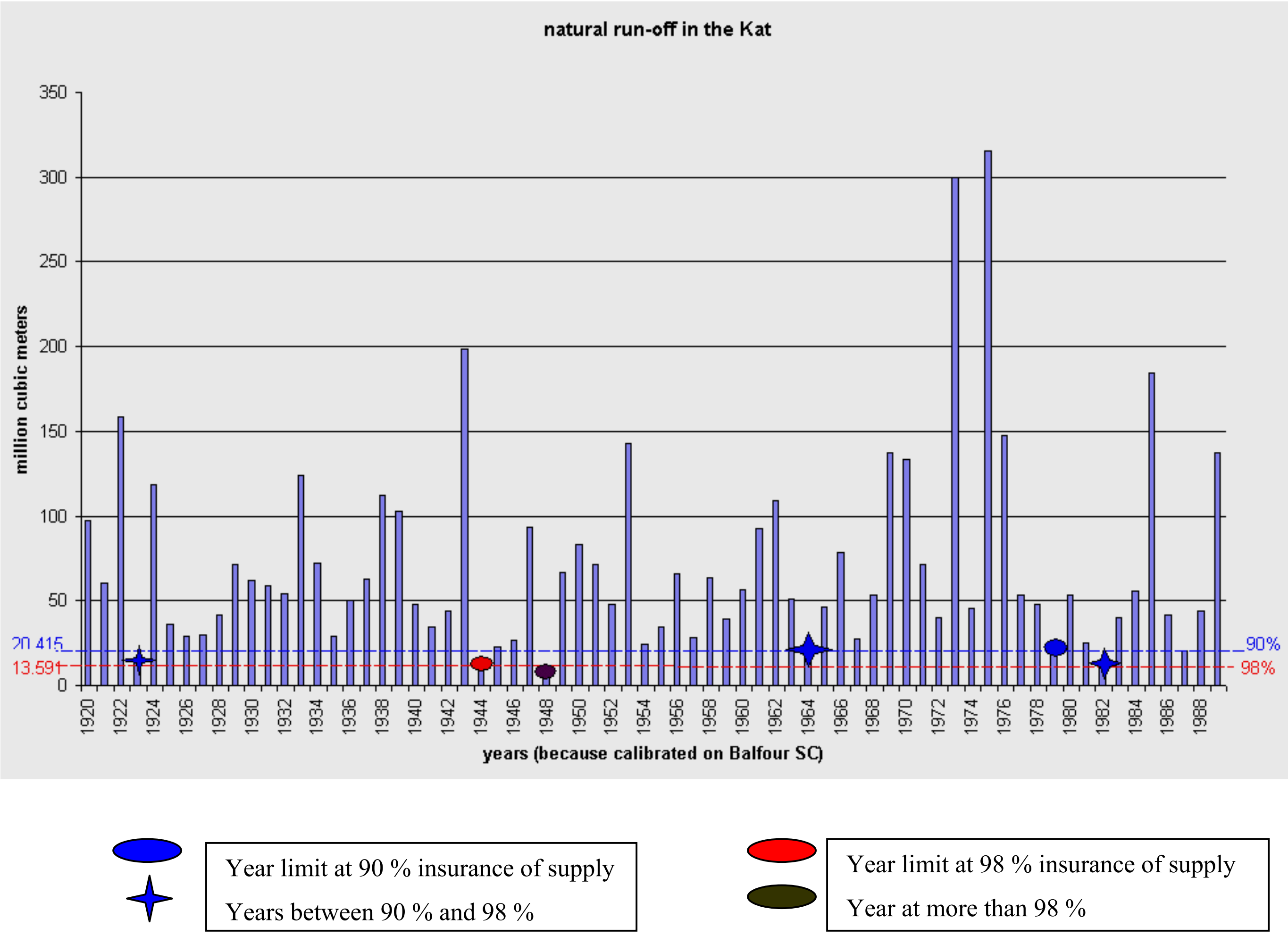
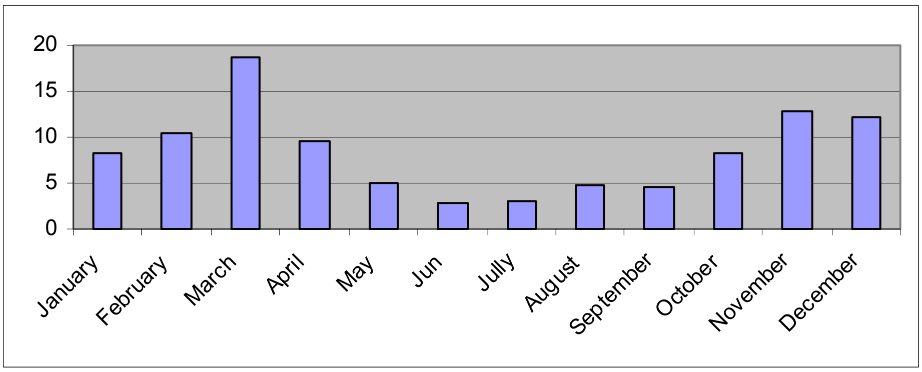


Figure 8 : Relative position of years chosen for natural run-off calculation



Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
8,18	10,43	18,62	9,54	4,92	2,82	2,98	4,81	4,64	8,21	12,76	12,09

Figure 9: Monthly rainfall distribution considered in Kat-AWARE V1 (percentage of annual)

Quaternaries	*SubCatchments*	Annual natural run-off (10^3 m^3)		
		90%	98%	more than 98%
Q94A	Dam	7 789	4 822	3 097
Q94E	Blinkwater	2 538	1 594	1 062
Q94F	Lower Kat	433	224	103
Q94F	Mxelo	269	149	80
Q94F	XuXuwa Kat	1 157	677	410
Q94D	Kat 4	490	291	164
Q94D	Mankazana	805	488	280
Q94D	Kat 3	791	441	265
Q94B	Tamboekiesvlei	355	232	147
Q94C	Balfour Buxton	3 171	1 958	1 330
Q94C	Kat 2	593	375	267
Q94B	Readsdale	2 242	1 386	876
Q94B	Upper IFR	99	58	30
Q94B	Kat 1	395	344	323
Q94	**Kat**	**21127**	**13039**	**8434**

Table 1: Sub-Catchments' annual natural run-off used in KatAWARE V1

3 CALIBRATION OF WATER DEMAND IN KatAWARE VERSION 1

3.1 Domestic users

A few changes have been made to domestic users' representation. Some *Villages'* positions, initialy obtained via the SA Explorer software system, were directly verified on the field by GPS ; Because results from field surveys were very similar to SA Explorer's values, *Villages'* positions were not modified. The only change is the removal of a *Village* that could not be identified. The list of the *Villages* considered in the model is presented in Annex 2.

Urban indwelling tap water users demand was replaced by a value of 7.6 m^3/month/capita in order to be sure not to underestimate domestic demand (this new value is closer to DWAF's estimation of urban indwelling water demand – DWAF, 2001). It is now possible to modify the rural indwelling tap water users' demand at each simulation in order to build scenarios.

3.2 Irrigators

3.2.1 Water and citrus production

With the introduction of individual water supply to each agent, it becomes possible to represent the impact that a water shortage has on a given agent. After long discussions and exchanges with agronomists and Kat large-scale farmers, a production function has been defined. This function calculates the monthly crop production for the annual cycle according to the quantity of irrigation water received and the quantity of water the crop needs.

The same function, validated for citrus by large-scale farmers, is used for citrus and cabbage *Crop Descriptions*. It is foreseen in future versions of the model to calibrate the parameters of the function to cabbage *Crop Description*.

Four different periods are defined along the annual cycle; to each period corresponds a coefficient (Ci in the following equations). "Ci" is the production yield (in % of the potential production) if no irrigation is provided during the period. At this stage, this coefficient is fixed at 1/3 for every period.

Using the following notations, yearly production "Py" is calculated as follows:

$$P_y = \sum_{m=1}^{12} P_m$$

P_m: production at month "m"

P_y: yearly production

The production at month "m" is calculated each month in the following way:

$$P_m = (1 - c_i) \times \frac{P_0}{d} \times \frac{Vr_m}{Vn_m} + c_i \times \frac{P_0}{d}$$

d: number of months requiring irrigation

c_i: coefficient of period "i" (always 1/3 in the model)

P_0: yearly production corresponding to full irrigation

Vr_m: volume of water received this month

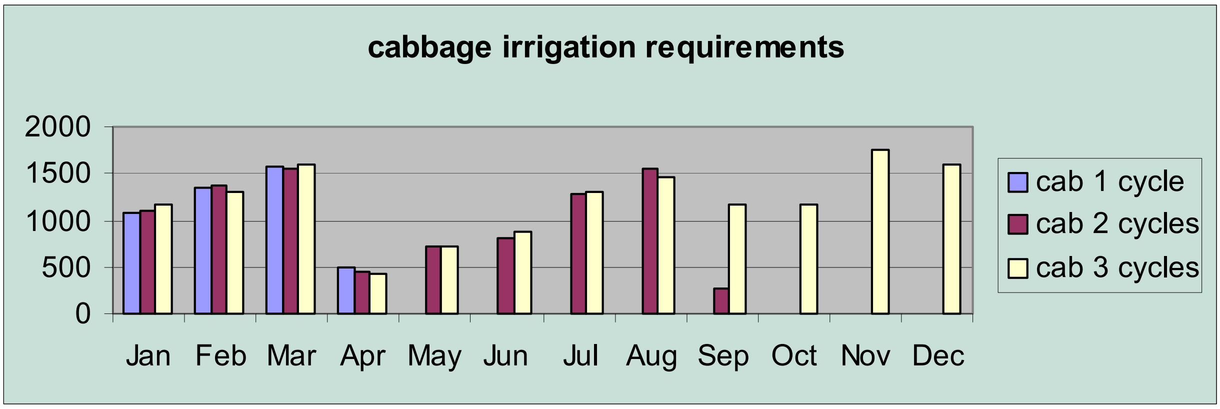
Vn_m: volume of water needed this month

3.2.2 New crop descriptions

In KatAWARE V1, like in KatAWARE P, Farmers choose their crops among a limited number of *Crop Descriptions*. In P, two *Crop Descriptions* were possible, one annual (cabbage) and one perennial (citrus). In V1, five *Crop Descriptions* were defined from the two first ones: three cabbage *Crop Descriptions* and two citrus *Crop Descriptions*.

3.2.2.1 Several cycles per year in cabbage Crop Descriptions

The three cabbage *Crop Descriptions* represent respectively one cycle, two cycle and three cycles of cabbage per year. They represent the practice, observed in the Kat, of producing several annual crops (mainly cabbage) on the same plot and therefore irrigating that plot all over the year (Burt et al., June 2005). Economic data were obtained by multiplying respectively by 1, 2 and 3, the data used for cabbage in KatAWARE P (one cycle). Monthly water needs (figure10) were obtained by the SapWat software system (Van Heerden et al., 2001).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*total*
Cabbage 1 cycle	**1075.2**	**1344**	**1568**	**492.8**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	***4480***
Cabbage 2 cycles	**1092**	**1365**	**1547**	**455**	**728**	**819**	**1274**	**1547**	**273**	**0**	**0**	**0**	***9100***
Cabbage 3 cycles	**1161.6**	**1306.8**	**1597.2**	**435.6**	**726**	**871.2**	**1306.8**	**1452**	**1161.6**	**1161.6**	**1742.4**	**1597.2**	***14520***

Figure 10 : Cabbage irrigation requirements (m^3/month/ha) in KatAWARE V1

3.2.2.2 Irrigation technologies and young trees water consumption in citrus Crop Descriptions

- **Irrigation technologies**

The two citrus *Crop Descriptions* represent a cropping system using a classic irrigation system (sprinkler) and a Cropping system using a high-performance water saving irrigation system (drip). Economic elements and yearly water needs of the plants for the two irrigation technologies were collected from local large scale farmers. Some values of the citrus budget have also been changed after interviews with large scale farmers; they appear in red in the new budget presented in figure 11. A capital cost has also been added to the budget. It is calculated as a percentage of the production costs:

*Capital_cost = 9 % * (prod_costs)*

Where production costs are: machinery costs, labour costs, general variable costs, water costs, investment costs (corresponding to crop implantation costs, mostly young trees and irrigation system) and land costs.

Irrigation water required is different for the two *Crop Descriptions*. Values used (table 2) come from Large-Scale farmers' direct surveys. Water needs distribution over a year is kept identical to the one in the prototype model.

Crop Description	Yearly consumption (m^3/year/ha)
Classic irrigation technology	7000
New irrigation technology	5500

Table 2: Citrus crops yearly irrigation requirements

- **Water need in growing period**

Young trees consume less water than mature ones. For that reason, a linear function was defined in collaboration with local large-scale farmers to calculate yearly irrigation requirements of immature citrus orchards in function of their age. The function is the following:

$$C_i = \frac{C_0 - 500}{d} \times (i-1) + 500$$

Where:

C_0: "crop description's" yearly consumption in mature period.

Ci : "crop description's" yearly consumption in immature period at age "i"

d: immature period's duration

1 Ha citrus budget				sprinkler	Drip
(in yellow, values used in citrus “crop description” or “markets”)					
COSTS					
	unit	quantity/y	R/unit/y	total/y	total/y
Fixed costs					
Installation costs*					
°Irrigation system		1		13000	17000
°Land Preparation		1		7500	7500
°Plants		1		10000	10000
°Plantation		1		2000	2000
*Installation costs**				*32500*	*36500*
Land					
°Land renting		1		2000	2000
Land cost				*2000*	*2000*
Main machineries					
°Tractor	% of availabilit	5,0%	6666,67	333,33	333,33
°Boom sprayer	% of availabilit	3,3%	6666,67	220,00	220
Machinery costs				*553,33*	*553,33*
Labour costs					
° Permanent	(h)	330,0	6,5	2145	2145
° Seasonal	(h)	360,0	7	2520	2520
° Casual	(h)	585,0	4	2340	2340
Labour costs				*7005*	*7005*
Variable costs					
labour costs approximation				115	115
Pesticides				4000	4000
Fertilisers				1700	1700
Fuel and Oper. Costs				2600	2600
Electricity				900	900
Repair/maintenance				1600	1600
small machinery				700	700
Variable costs				*11615*	*11615*
financial costs (9% of production costs)				*1997,01*	*2008,26*
total production costs (including financial costs)				***24185,96***	***24322,21***
Commercialisation costs					
° International market	(t)	31,5	1250	39375	39375
° local market	(t)	13,5	446	6021	6021
Commercialisation costs				*45396*	*45396*
total costs				**69581,96**	**69718,21**
INCOME					
		quantity	market price	total	total
production	tons	45			
sells					
° international market	tons	31,5	2500	78750	78750
° local market	tons	13,5	833	11245,5	11245,5
total income				**89995,5**	**89995,5**
total profit				**20413,54**	**20277,29**

*Installation costs are payed over a 32 years period

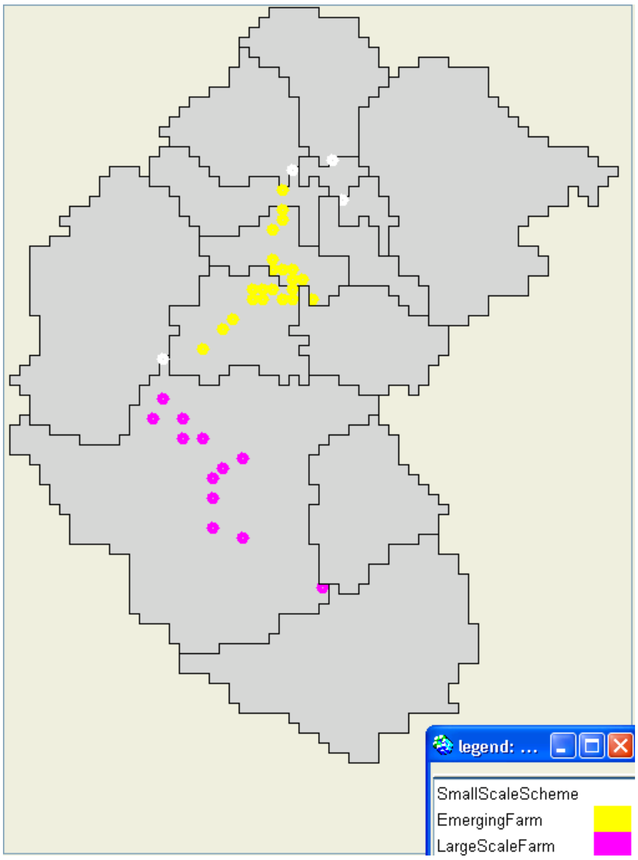
Figure 11: Budget used to build new citrus Crop Descriptions

3.2.2.3 New position of Farms

Citrus *Farms* (*Large-Scale* and *Emerging Farmers*) were placed according to a land-use map referring to 1996 and obtained from CSIR. Cabbage *Farms* were also slightly moved according to discussions with local stakeholders. A new cabbage *Farm* was also introduced in the XuXuwa Kat.

On one hand, citrus *Farms'* position is now very accurate; this is confirmed by the reaction we had from the large-scale farmers in the Kat. On the other hand, it would be important to verify with accuracy the position of the Small-Holder *Farms* to be sure in which *Sub-Catchment* they are (in fact, the *Farms* are near the *Sub-Ctchments'* limits). This fact has an influence on the possibility of the agents to withdraw water from the main river or from a tributary. In V1, according to the data available, all *Farms* have been positionned in *Sub-Catchments* corresponding to the main river's path.

Position and surface of Kat-AWARE V1's *Farms* are presented in figure 12.



Sub-Catchment	Farms & crops	surface
Kat 1	1 small-holder (cabbage 3 cycle)	40 ha
Upper IFR	1 small-holder (cabbage 3 cycle)	40 ha
Kat 2	1 small-Holder (cabbage 1 cycle)	40 ha
	1 emerging (citrus classic)	18 ha
Kat 3	10 emerging (citrus classic)	180 ha (10x18)
Kat 4	11 emerging (citrus classic)	198 ha (11x18)
XuXuwa Kat	1 small-Holder (cabbage 3 cycle)	60 ha
	12 large scale (citrus classic)	870 ha (300+5x24+30 +60+ 4x90)
Kat river	**4 small holders, 22 emerging, 12 large-scale**	**1446 ha**

Figure 12: Farms in KatAWARE V1

4 INTRODUCING A FRAMEWORK FOR WATER LICENCE MODELLING

4.1 Water licensing process

Water licensing is planned to be organized in the Kat as in every other South African catchment as indicate in the National Water Act of 1998. Water licences define the way a user is entitled to use water (quantity, frequence…). Licences must be limited in time and renewable.

In order to model the future implementation of those regulations, a process was build in KatAWARE V1, which allows *Farmer* agents (and not *Villages* agents for the moment) to take into account the *Water User Association* entity decisions in their own decision making. This process occurs at the beginning of each year (yearly time step) and is schematised in the three points indicated below.

At this stage, the WUA strategy is not defined yet. For this reason, in Kat-AWARE V1, the *WUA* entity allocates to each agent, the *Water Licence* he asked. This means that the process described below is implemented in V1 but has no effects. It only proposes a framework for the implementation of the next Kat-AWARE model.

How the Municipality strategies can affect *Villages* is not clearly defined and that is the reason why *Villages* are not incorporated in this process. As said previously, they implement their decisions without any regard to the *Water Licence* allocated to the *Municipality*.

1. <u>Personal decisions and *Water Licences* demands</u>

In that phase, each agent formulates its decision according to its personal strategy. For exemple, replacing a crop by another on a given surface (*Farmers* agents), or changing a water source type for another in a *Village* composition (*Villages* agents).

Villages always evolve according to the decision they took. *Farmers* not necessarily (see step 3) , they only save the decisions they made (as *Planting Decisions*).

Following these decisions and their initial situation, agents (*Farmers* and *Municipality*) estimate the quantity of water they will need during the following year and send *Water Licence Demands* to the *WUA* entity.

2. <u>*Water Licences* allocation by the *WUA* entity</u>

At this stage, the *WUA* entity receives all the *Water Licence Demands* for the following year from the agents. These demands can be converted by the WUA into *Water Licences* to be distributed to the agents (*Municipality* and *Farmers*).

3. <u>Reconsidering the decisions according to the *Water Licence* received and implementing the new decisions</u>

Once *Farmer* agents have received their licences for the year, they verify if they will be allowed to use enough water to implement the decision they made (*Planting Decision*). If they receive the licences they asked for, then, they implement their initial decisions. What occurs in the opposite case has not yet been implemented in Kat-AWARE V1.

4.2 Paying for Water

In the present real world of the Kat catchment, only scheduled users pay for water rights, depending on the surface they own within the scheduled area.

In Kat-AWARE V1, water rights are paid via *Water Licences*. *Farmers* having the "*scheduled*" characteristic buy their *Water Licences* from the *WUA* at the beginning of each year. U*nscheduled Farmers* do not pay for their *Water Licences,* neither do *Villages*. The *Municipality* entity pays its *Water Licence* a price corresponding to its estimation of *scheduled Villages* consumption for the next year. The licences' prices are calculated by multiplying the water needed for the year by a constant price (0.05 R/m^3/year) (Farolfi & Abrams, 2005).

In the model, as in the reality, scheduled users do not necessarly use the whole amount of yearly water from the *Dam* for which they are entitled and pay.

5 SCENARIOS

Kat-AWARE is a simulation model. In P, the model offered a limited range of scenarios. In V1, it is possible to easily change a certain number of variables before each simulation. The resulting combination of the set variables allows producing a large amount of scenarios.

6.1 Initialising set up

An important characteristic regarding the rights to water use can be set up in order to modify the initial situation. As said previously, by default only a limited number of *Farms* are *scheduled*. It is possible now to run simulations in which all *Farms* situated on the main river are *scheduled*.

6.2 Parameters for agents' evolutions

According to the initial situation chosen, different characteristics can be set up regarding the agents' evolutions.

Two main scenarios have been implemented: One in which agents do not evolve during the whole simulation and another in which agents have evolution patterns that can be modified as it is explained in the following paragraphs. Annex 1 presents the scenario setups interface.

6.2.1 Irrigated citrus land extension

Each yearly time step, *Farmers* can extend their *Farms*' surfaces by planting new *Cropping Systems*. For citrus *Farms*, a yearly extension coefficient is calculated so that the scheduled surface (surface irrigated by *scheduled Farms*, citrus or cabbage) matches a given surface at the end of the evolution period (5 years by default, but it can be modified).

The scheduled surface to match is set up by default at 1500 ha because it is the surface initially planned to be supplied with irrigation water by the *Dam*. To test different scenarios, it is possible to change this surface. By doing that, the model changes accordingly the yearly extension coefficient. If all *Farms* are *scheduled*, this surface corresponds to the total irrigated surface. If conversely southern citrus *Farms* are unscheduled, it is possible either to make them evolve the same way as scheduled *Farms* (using the same yearly extension coefficient), or not to make them evolve.

6.2.2 Domestic evolution

Domestic evolution is the same as in Kat-AWARE P. For each scenario, it is possible to consider a domestic evolution or not. As indicated previously, it is also possible to change the amount of water consumed by rural households when indwelling tap is available.

6.2.3 Smallholders' evolution

Three possible evolutions are defined for small-holders *Farms*: 1) change their whole production into citrus, 2) double their cabbage's surface or 3) do not change anything.

6.2.4 New technology implantation in citrus Farms

At the beginning of the simulation, all citrus *Cropping Systems* use a classic irrigation system consisting in a sprinkler (Classic irrigation system *Crop Description*). It is possible to simulate the situation where all newly planted citrus *Cropping System* use the water saving irrigation system *Crop Description*. This is represented by a drip system.

6.2.5 Water supply scenarios

As indicated previously, it is possible at the beginning of each simulated year, to choose the yearly catchment rainfall among three levels of insurance of supply: 90%, 98% or more than 98%.

7 OUTPUT REPRESENTATION

7.1 Simulation interface

The interface used to show KatAWARE V1 simulations is very similar to the one used in the prototype (figure 13). This choice was made to allow local stakeholders already familiar with KatAWARE P to switch in a relatively easy way to KatAWARE V1. The main change is the replacement of the three representative quaternaries' histograms by a single graph indicating for the whole catchment each month the amount of water available (water stored + water from rain) and the amount of water consumed (total water consumed during the month).

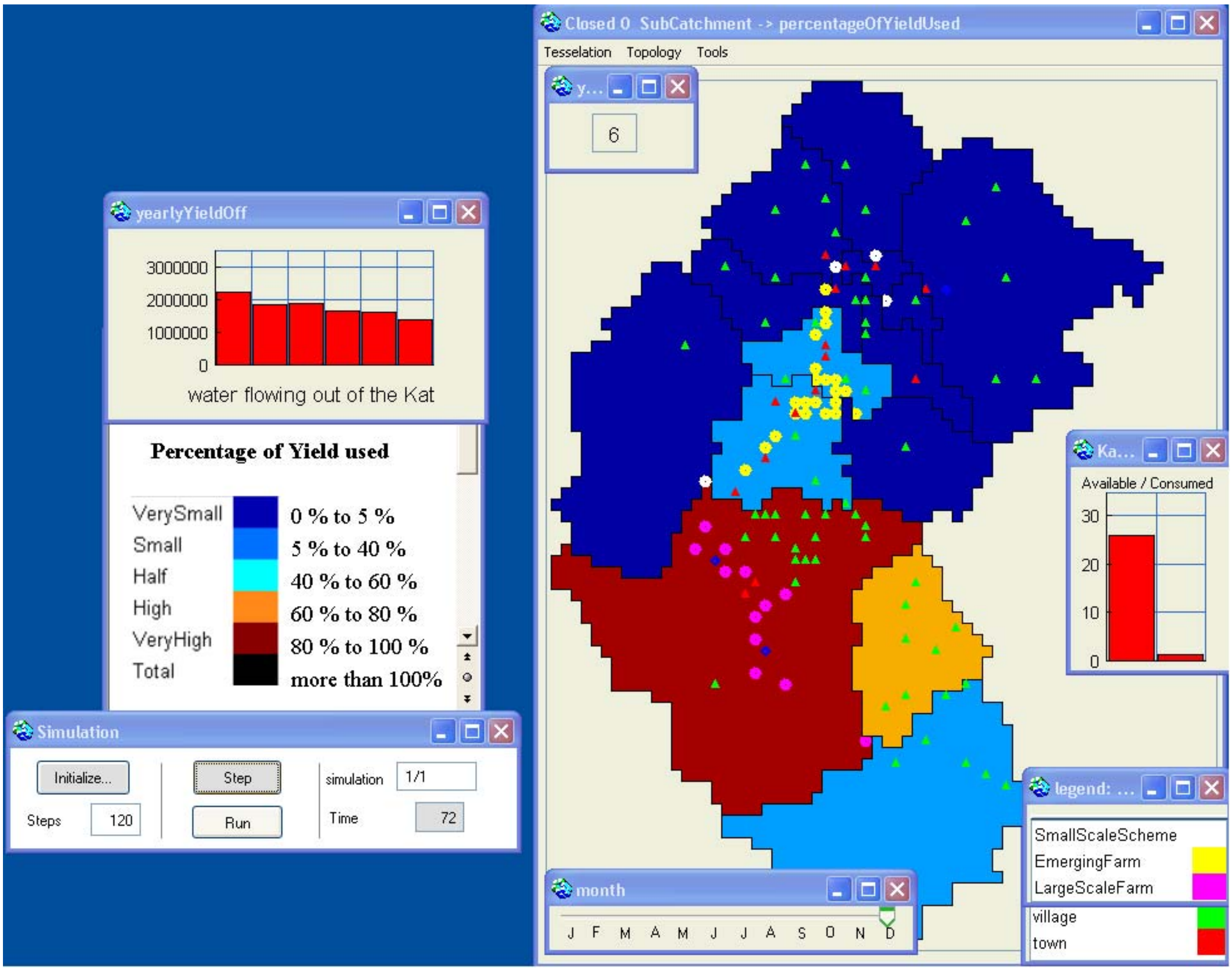


Figure 13 : Simulation interface in KatAWARE V1

The *Sub-Catchments* have also been changed. However, version 1 allows to have a *Quaternary* point of view and to have access to all information aggregated to the quaternary scale via graphs as it was possible in the prototype (water consumption, water demand, water supply and socio-economic values).

7.2 *Inspecting agent interface*

A new point of view is possible stopping the simulation at any moment. This point of view (figure 14) shows the river path and all agents' icons. It allows having immediate access to the information concerning each agent (see the exemples of *Farm* budget and *Village* card) by "clicking" on its icon on the map.

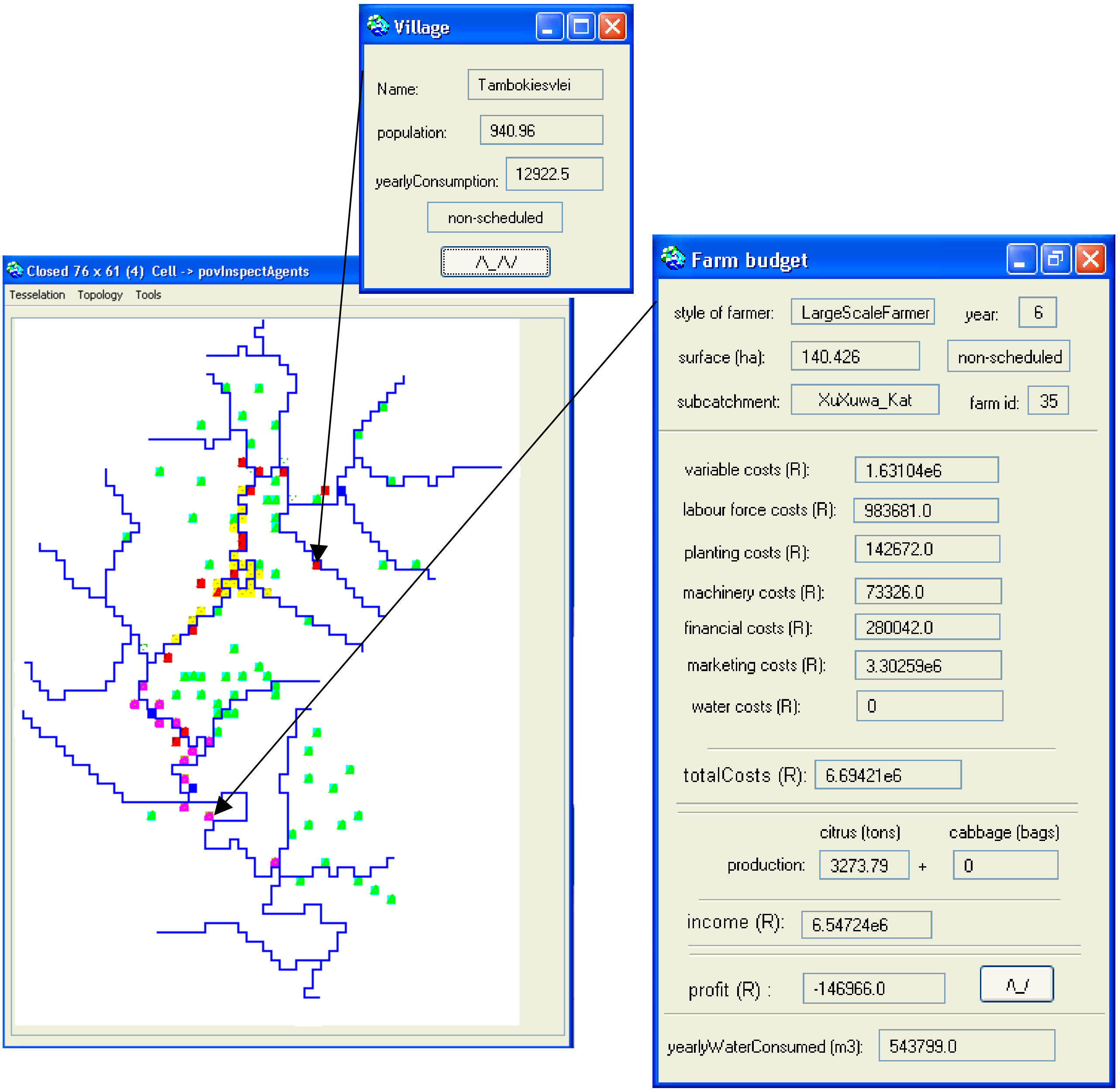


Figure 14: Inspect agent point of view

7.3 *Graphs*

It is finally possible, as in the prototype, to observe evolution graphs at the agents' or Sub-Catchments' scale. By this way it is now possible to compare the demand of each agent with its consumption (figure 15) and to observe the impact a water shortage can have on the production (figure 16).

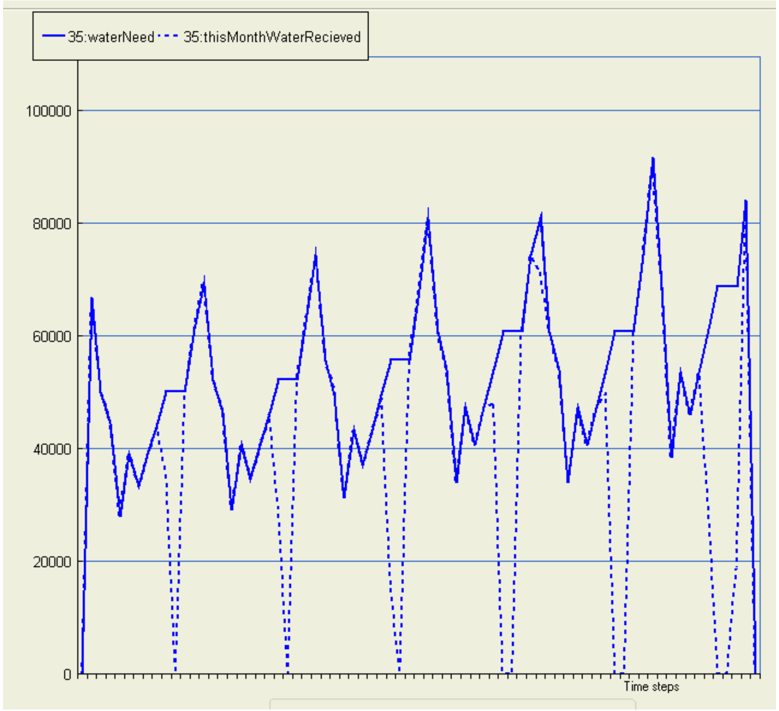


Figure 15: Farm 35 water needs and water received in a water stress scenario

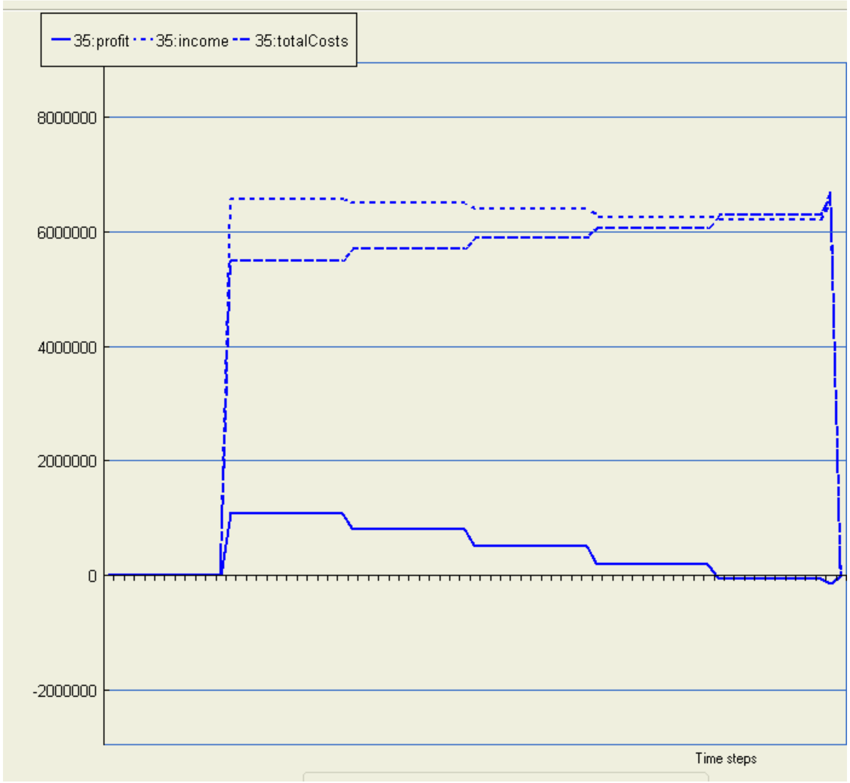


Figure 16: Farm 35 basic economic values in a water stress scenario

Figure 17 presents the Seymour *Dam* level over a ten-year simulated period in a scenario where all users are *scheduled* (can ask water from the *Dam*), the demand is the same year after year and the supply changes (the first 3 years at 98% assurance of supply, the second 3 years at "more than 98%" and the last 4 years at 90%)

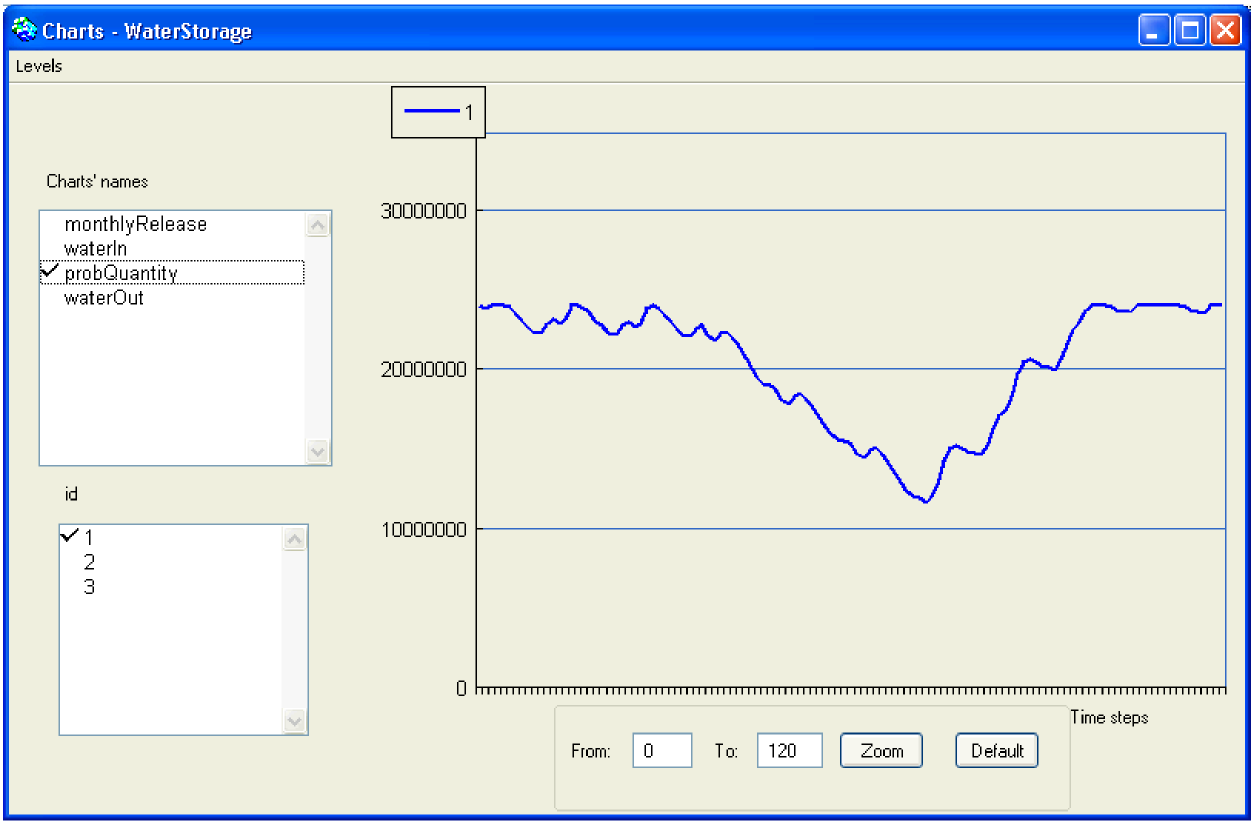


Figure 17 : Seymour Dam level dynamics

References

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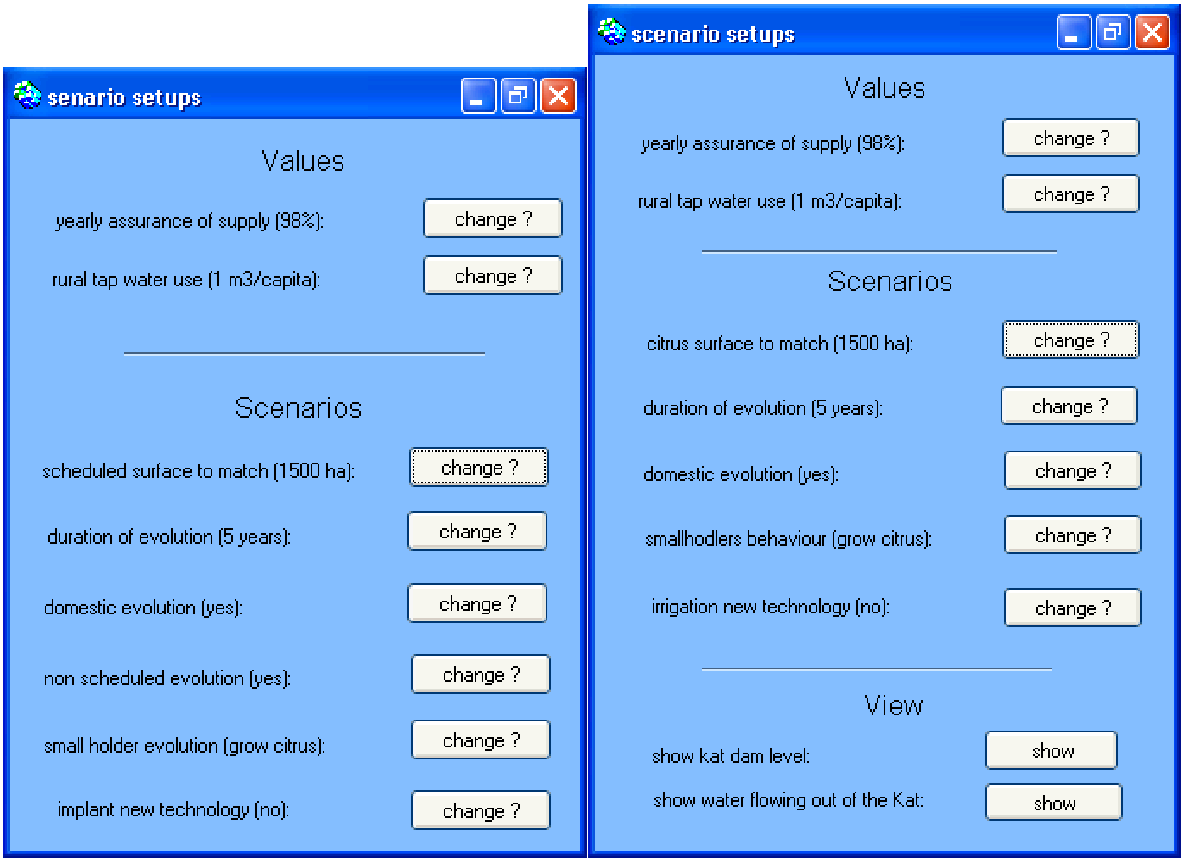
Annexes

Annex 1: Scenarios set up interface



Scenario set up interfaces

Annex 2: Residential centres corresponding to Kat-AWARE *Villages* (SA Explorer)

Place Name	Village or town[1]	Scheduled
Bevalle	village	no
Calderwood	village	no
Elundini	village	no
Healdtown	village	no
Imingcangathelo	village	no
Kwezana East	village	no
Lebanon	village	no
Lower Sheshegu	village	no
Luzini	village	no
Mantelenteleni	village	no
Mphateni	village	no
Mpozisa	village	no
Ndaba	village	no
Nduveni	village	no
Ngcelwane	village	no
Nobanda	village	no
Thembisa	village	no
Tidburys Toll	town	no
Xolani	village	no
Amherst	town	no
Bellvale	village	no
Benholm	village	no
Bulura	village	no
Buxton Forest	village	no
Carthcartvale	village	no
Cranford	town	no
Flanagrans Drift	town	no
Fort Amstrong	village	no
Gonzana	town	no
Hertzog	village	no
Jelluman's Kloof	village	no
Jurieshoek	village	no
Katriver Dam	village	no
Killarney	village	no
Lamyeni	village	no
Lloyd	village	no
Maasdorp	village	no
Mount Ruby	village	no
Ngwevu	village	no
Oakdene	town	no
Orange Grange	village	no
Phillipton	village	no
Riverside	village	no
Roxeni	village	no
Rwantsana	village	no
Tambokiesvlei	town	no
Teba	village	no
Tinis	village	no
Tyatyora	village	no
Upper Blinkwater	village	no
Upsher	town	no
Venture	village	no
Fairbairn	town	no
Katberg	village	no
Lushington	village	no
Mankazana	village	no
Mckomershoek	village	no
Mlalandle	village	no
Mpofu	village	no
Ntilini	town	no
Picardy	town	no
Readsdale	village	no
Sikolweni	village	no
Buxton	village	no
Fort Beaufort (Rural)	village	no
Newtown	town	yes
Ntoleni	village	no
Victoria East (Rural)	village	no
Katberg Forest	village	no
Sigingqini	village	no
Fort Beaufort	town	yes
Seymour	town	no
Balfour	town	no
Bhofolo	village	no
pop of this ward	village	no

[1]As in Kat-AWARE P, 80% of the population is in the *Villages* “town” and 20% in the *Villages* “villages”